

A LARGE, COLD, AND UNUSUAL MOLECULAR CLOUD IN MONOCEROS

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ABSTRACT

Observations of the $J = 1 \rightarrow 0$ rotational transition of CO near the galactic plane in Monoceros ($l \approx 216^\circ$) reveal a molecular cloud with unusually low peak CO temperatures ($T_R < 2$ K) but wide lines (~ 7 km s $^{-1}$) typical of much warmer clouds. At the assumed distance of 3 kpc, the cloud is large (250×100 pc), has a mass of $7\text{--}11 \times 10^5 M_\odot$, and is well removed from the galactic midplane (130 pc). Except for a possible H II region, all the signs of star formation usually shown by clouds of comparable mass are missing. The cloud, unlike cloud complexes of similar size, is a single, continuous object that apparently has not been torn apart by star formation. Clouds with such properties are rare in the Galaxy; only one or two similar objects have been found. We discuss the possibility that the cloud is young and not yet forming stars but will evolve into a typical cloud complex once star formation begins.

Subject headings: interstellar: molecules — stars: formation

I. INTRODUCTION

Investigations of individual molecular clouds often suffer from an observational bias: usually the clouds selected for study are located near H II regions, OB associations, infrared sources, reflection nebulae, or some other recent product of the formation of fairly massive stars. Little attention has been given to clouds that show no conspicuous star-forming activity, although there is evidence that such clouds exist. For example, Myers *et al.* (1985), comparing the unbiased Columbia CO survey of distant objects in the inner Galaxy with far-infrared, radio-continuum, and radio recombination-line surveys, showed that the number of young stars that accompany large molecular clouds fluctuates greatly and that some large clouds display little or no evidence of star formation. In the large Orion complex several long filaments, detected so far only in CO and well removed from the prominent regions of star formation, show no star-forming activity at all (Maddalena *et al.* 1985).

Recently a large molecular cloud apparently devoid of star formation was found with the Columbia millimeter-wave telescope during a CO survey of the galactic plane in the third quadrant of the Galaxy. The location of this cloud is 2.5° below the galactic plane and midway between the Rosette and CMA OB 1 cloud complexes (Blitz 1979a; Blitz and Thaddeus 1980). Figure 1 gives the location of this cloud and of all major CO clouds found to date in the third quadrant by the Columbia telescope. The newly discovered cloud, if at a distance of 3 kpc (§ IIIa), is larger than the other clouds in Figure 1 even though it covers less angular area than the closer clouds associated with Orion A, Orion B, Monoceros R2, and Taurus. In Figure 1 the Orion complex of clouds is the only object comparable to the new cloud in size and mass (§ IIIa–b). While these smaller, nearby molecular clouds show much evidence of associated star formation, the newly discovered object shows very little (§ IIIc). These properties, as well as the cloud's low temperature and wide spectral line widths (§ II), are rarely found in combination for other molecular clouds (§ IIId). We propose, first, that the new cloud may be a young object which has not yet extensively formed massive stars and, second, that in appear-

ance, after massive stars form, it may resemble the Orion complex (§ IIIe).

II. OBSERVATIONS

The 1.2 m Columbia millimeter-wave telescope has an 8.7° beamwidth (HPBW) and, with a filter bank of 256 channels each 250 kHz wide, a velocity resolution of 0.65 km s $^{-1}$ at the 115 GHz, $J = 1 \rightarrow 0$ line of CO. Midway through the observations, a room-temperature Schottky diode receiver was replaced by a recently developed and extremely sensitive cryogenic receiver with a superconductor-insulator-superconductor (SIS) junction. See Appendix for details on the receivers, observational technique, calibration, and telescope pointing.

The observations are summarized in Figures 2, 3, and 4. Figure 2 gives the spatial distribution of W_{CO} (K km s $^{-1}$), the velocity-integrated intensity of CO emission, and the positions of observation. Other than the newly discovered cloud located at $l = 216^\circ$, $b = -2.5^\circ$, Figure 2 shows a few small clouds with low-intensity CO emission and a significant molecular cloud located at $l = 218^\circ$, $b = 0^\circ$, associated with the optical H II region S287. The new object has properties different from the S287 cloud and other typical molecular clouds found throughout the Galaxy. Its T_R rarely exceeds 2 K (significantly less than the 5 K typical for envelopes of large molecular clouds), yet its spectral line widths (~ 7 km s $^{-1}$ FWHM) are as wide as those found toward the small emission peaks in the Orion molecular clouds where temperatures are far higher (Maddalena *et al.* 1985). Figure 3 gives both the averaged spectrum and a typical observed spectrum for this cloud. Spot checks of CO and ^{13}CO with the 4.9 m radio telescope at McDonald Observatory, University of Texas, yielded CO temperatures in agreement with ours, indicating that the observed T_R reflects a low kinetic temperature for the cloud rather than effects of clumping.

The cloud covers nearly 6 deg 2 of sky, and its velocity with respect to the local standard of rest (v_{LSR}) is 27 km s $^{-1}$. Figure 4, a velocity-longitude diagram for the cloud, shows a velocity gradient from $v_{\text{LSR}} = 25$ km s $^{-1}$ at $l = 215^\circ$ to $v_{\text{LSR}} = 32$ km

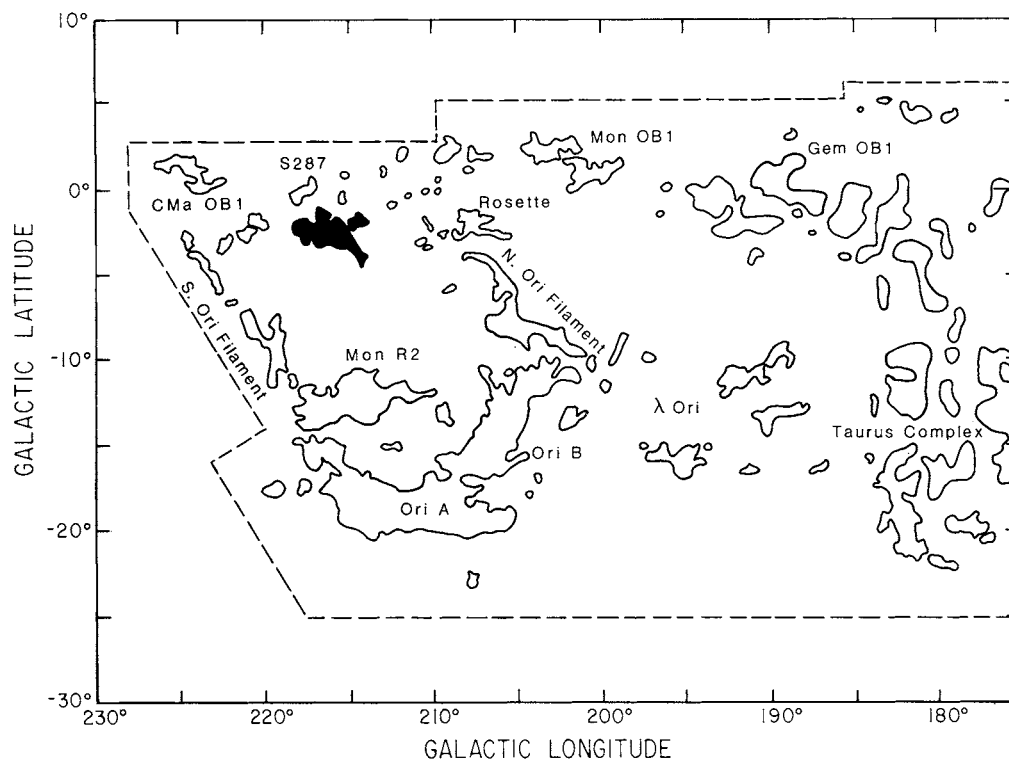


FIG. 1.—The larger molecular clouds found by the Columbia millimeter-wave telescope in the third galactic quadrant (Blitz 1979a; Blitz and Thaddeus 1980; Baran 1983; Huang 1984; Maddalena *et al.* 1985; this work). The cloud discussed here is shaded in. All molecular clouds larger than 0.5 deg^2 in area and with $W_{\text{CO}} > 2.5 \text{ km s}^{-1}$ and located within the outlined region have probably been found.

s^{-1} at $l = 219^\circ$, close to that expected from differential galactic rotation.

III. DISCUSSION

a) Distance and Size

Using the flat rotation curve determined by Blitz (1979b), we obtain a kinematic distance of 2.7 kpc for the velocity and galactic coordinates of the new object. Because this rotation curve is based on few observations inside the region $205^\circ < l < 225^\circ$ with distances greater than 1.5 kpc, the uncertainty in the distance is probably as large as 1 kpc. Further evidence for this distance comes from S287, the H II region located nearby at $l = 218.1^\circ$, $b = -0.4^\circ$, which has a photometric distance of 3.2 kpc (Moffat, Fitzgerald, and Jackson 1979). The agreement between the radial velocity of the new cloud and that of the molecular cloud associated with the H II region (27 km s^{-1} ; also Blitz, Fich, and Stark 1982) suggests the two are at about the same distance.

The proximity between the S287 cloud and the main cloud in Figure 2 and the similarity in cloud velocities both suggest that these clouds are part of the same complex, but since no emission appears to connect them it is possible that they are unrelated. Both the S287 cloud and the main cloud appear to be part of a more extensive arrangement of third-quadrant clouds, with the galactocentric distance expected for a third-quadrant extension of the Perseus arm of the Galaxy. All these clouds may lie within the Perseus arm.

The open cluster NGC 2286, at 1.28 kpc (Becker and Fenkart 1971), is within the cloud boundary at $l = 215.3^\circ$, $b = -2.3^\circ$. The low color excess (0.41 mag) for the stars in the cluster and the age of the cluster (10^8 yr), determined from the

earliest spectral type found within the cluster, indicate that the cluster is a foreground object unrelated to the cloud.

In Figure 1 the fairly small angular separation between the new cloud and those associated with the Rosette Nebula (distance = 1.6 kpc, Turner 1976; velocity = 15 km s^{-1} , Blitz and Thaddeus 1980) and CMa OB 1 (distance = 1.2 kpc, Eggen 1978; velocity = 18 km s^{-1} , Blitz 1979a) suggests that the new cloud might be related physically to either set of objects, but the velocity discrepancy of about 11 km s^{-1} probably rules this out. Although its size and mass would be significantly smaller than those derived below if the distance were 1.2 kpc instead of 3 kpc, this cloud would remain an unusual object.

At 3 kpc, the new cloud is one of the largest molecular clouds known, with a major axis of 250 pc and a minor axis of 100 pc. The outer Galaxy is not warped at this location (Henderson, Jackson, and Kerr 1982), so its galactic latitude probably corresponds to a true displacement from the galactic midplane. The displacement is unusually large: 130 pc or about 1.5 times the half-thickness at half-maximum of molecular material at the solar circle (Thaddeus and Chanan 1985).

b) Masses

We derived a mass for the cloud by assuming, first, that the cloud is in virial equilibrium and, then, that the column density of H_2 , $N(\text{H}_2)$, is proportional to W_{CO} .

For a uniform, spherical cloud of radius R in virial equilibrium, $M_{\text{vir}} = 5R\Delta V^2/[8G \ln(2)]$, where G is the gravitational constant and ΔV is the FWHM velocity dispersion of gas in the cloud. We assumed that ΔV is the FWHM of the averaged CO spectrum (Fig. 3a) and that the radius $R =$

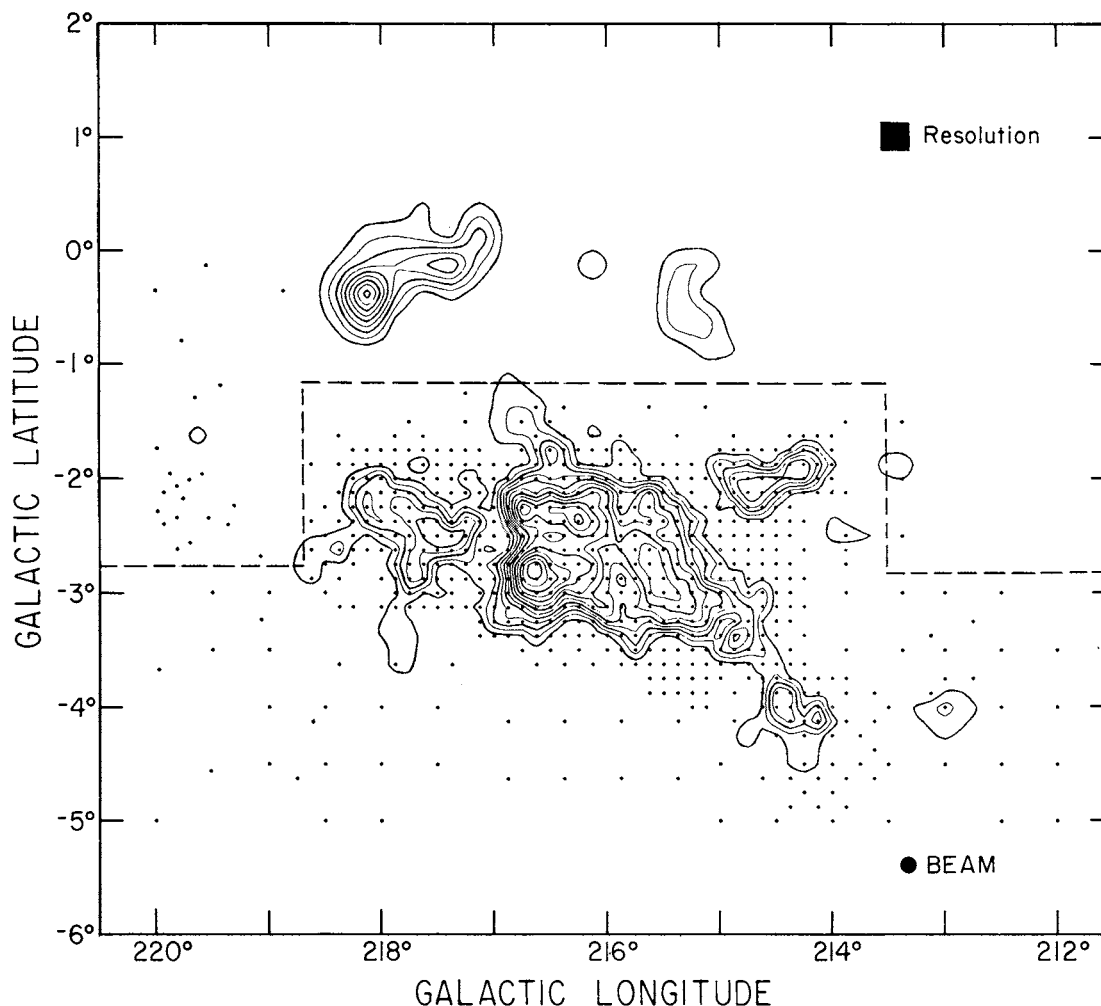


FIG. 2.—A map of the new, quiescent cloud and its vicinity that shows integrated CO emission, W_{CO} , in the velocity range of 15 to 40 km s^{-1} . The lowest contour level and the increment between levels are 1.3 K km s^{-1} . Dots indicate the positions of observations at full angular resolution: $8''.7$. To shorten the time needed to sample the region north of the dotted line fully, we reduced the resolution of the telescope to an approximately square beam $0''.25$ on a side by stepping the telescope through a two-by-two grid during data acquisition.

$(A/\pi)^{1/2}$, where A is the area within the lowest contour level of Figure 2. Taking $A = 1.6 \times 10^4 \text{ pc}^2$ and $\Delta V = 8.5 \text{ km s}^{-1}$ as measured, then $M_{\text{vir}} = 10.8 \times 10^5 M_{\odot}$, which, omitting effects of unknown density or magnetic field structure and internal sources of pressure, is an upper limit to the cloud's mass. Sources of pressure within the cloud (interactions either with H II regions or with strong stellar winds from young stars) seem to be absent (§ IIIc), so M_{vir} is probably more realistic for this cloud than for others.

Empirically, W_{CO} appears to be a reliable estimator of $N(\text{H}_2)$ (see, e.g., Liszt 1982; Lebrun *et al.* 1983; Kutner and Leung 1984). Bloemen *et al.* (1984) calibrated the $N(\text{H}_2)$ -to- W_{CO} ratio toward Orion by using COS B γ -ray observations, the Berkeley 21 cm surveys, and the Columbia CO observations; they find $N(\text{H}_2)/W_{\text{CO}} = 2.6 \pm 1.2 \times 10^{20} \text{ cm}^{-2} (\text{K km s}^{-1})^{-1}$. Assuming the mean atomic weight is 1.36 per hydrogen atom and that all hydrogen is molecular in form, we find for the new cloud that $M_{\text{CO}} = 6.6 \times 10^5 M_{\odot}$. Errors of order 50% are intrinsic to both methods, so the agreement between M_{vir} and M_{CO} is quite good.

As Figures 2 and 4 show, a dip in CO emission and a change in cloud velocity occur along a north-south line at $l = 217.2$.

While it seems unlikely that the cloud is two physically unrelated objects, we calculated masses for each. Table 1 reviews the parameters of the cloud, compares the various masses, and gives estimates for the mass of the S287 cloud. Notice that the region with $l > 217.2$ and the S287 cloud are not very massive.

c) Associated Objects

The POSS prints for the location of the cloud show a slight trace of optical obscuration, which is consistent with the cloud's large distance and with most observable stars in the foreground. Khavtassi (1955) notes a dark cloud subtending about 3 deg^2 in the same general region. The newly discovered object coincides with a region of H I enhancement (Weaver and Williams 1973) and an excess of γ -ray emission which cannot be entirely accounted for by the interaction of cosmic rays and the gas implied by 21 cm observations (Bloemen *et al.* 1984). The cloud is not a source of infrared emission; in the direction of the cloud all cataloged infrared sources have been attributed to nearby stars (Neugebauer and Leighton 1969; Walker and Price 1975; Longmore, Hyland, and Allen 1976; Price and Walker 1976).

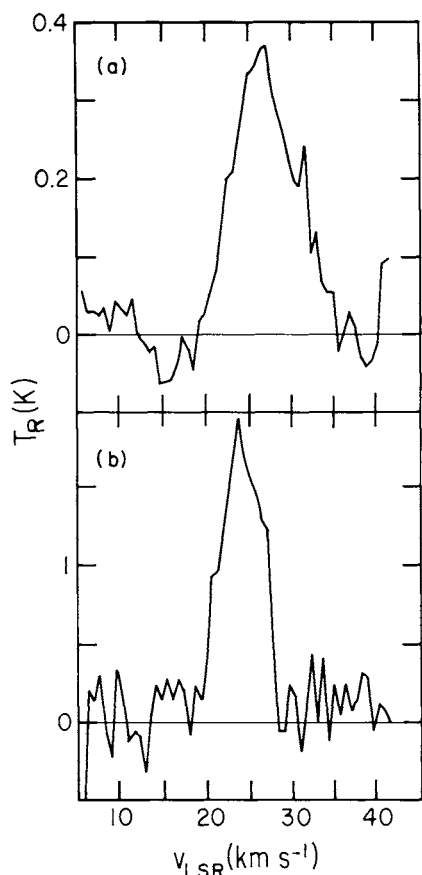


FIG. 3.—(a) Average spectrum obtained by integrating observations over solid angle for all positions with $b < -1^\circ$. (b) CO spectra at $l = 216^\circ 375$, $b = -2^\circ 75$, typical of those found toward the cloud.

Low-mass stars, T Tauri stars, or Herbig-Haro objects would be difficult to detect because of this cloud's large distance. If H II regions or OB stars exist on the near side of the cloud, they should be visible; the cloud is itself optically visible, and S287, lying on the galactic plane where foreground obscuration is presumably the same or higher, is easily seen. There are no H II regions or OB stars toward this cloud in the standard catalogs (Sharpless 1959; Goy 1973; Cruz-Gonzales *et al.* 1974; Marsalkova 1974; Humphreys 1978).

Since radio-continuum surveys can detect obscured H II regions, we checked to see whether any were detected by surveys that observed the general area of the molecular cloud (see Table 2). First, we determined whether the continuum sources located in the direction of the cloud have the thermal spectrum indicative of an H II region. Second, we found excitation parameters for the H II regions, $u(\text{pc cm}^{-2})$, equal to $K(\nu, T) [D(\text{pc})^2 S_\nu(\text{Jy})]^{1/3}$, where D is the distance to the H II region and S_ν is the observed flux density. $K(\nu, T)$, which depends on the temperature assumed for the H II region ($\sim 10^4$ K) and only slightly on the frequency of observation, equals 13.5 for $\nu = 1415$ MHz (Hjellming 1968). We assumed that the H II region is unresolved, ionization-bounded, and optically thin at the frequency of the observations used to find u . Last, we used u to ascertain the number and type of O or B zero-age main-sequence (ZAMS) stars responsible for the H II region (Panagia 1973).

A proper analysis depends on whether the possible H II region is optically thin at the frequency used to calculate u . The radio surveys completed toward this cloud remain inadequate to determine optical thickness, and the sensitivities of these surveys are low; at 3 kpc, only H II regions excited by stars earlier than a B0 star could have been detected. Table 2 presents preliminary estimates of u and stellar spectral types; all need to be checked by surveys of higher sensitivity.

Of the five continuum sources detected toward the molecular cloud, only 4C -02.28 appears to be an H II region which, if at a distance of 3 kpc, may be excited by an O6 ZAMS star. Recombination-line studies toward 4C -02.28 could test whether any relation exists between the cloud and the H II region; if the H II region is unrelated to the molecular cloud, then recombination-line observations may find a radial velocity for the H II region different from the cloud's velocity.

d) Clouds with Similar Properties

To estimate the number of clouds in the Galaxy with properties similar to those of the new cloud, we searched the extensive Columbia CO surveys of the first, second, and third quadrants for clouds devoid of star formation with masses greater than $10^5 M_\odot$ and lines weaker than 2 K and wider than 6 km s^{-1} .

Within 1 kpc of the Sun, large molecular clouds, whose spectra typically have higher T_R and narrower line widths than those found toward the new cloud, are invariably associated with extensive star formation. Although the Orion molecular filaments (see Fig. 1) have wide lines but no star formation, their masses are an order of magnitude less than the new cloud's (Morris, Montani, and Thaddeus 1980; Maddalena *et al.* 1982; Thaddeus 1982; Maddalena, Morris, and Bally 1985). We find no evidence for similar clouds in the Perseus arm (Gottlieb, Brock, and Thaddeus 1984) or elsewhere in the second and third quadrants (Blitz 1979a; Blitz and Thaddeus 1980; Baran 1983; Huang 1984; Maddalena *et al.* 1985).

The analysis of large cloud complexes in the first quadrant by Dame *et al.* (1985) is generally limited to clouds with a total CO luminosity ($S_{\text{CO}} = \int W_{\text{CO}} d\Omega$) of $8 \text{ K km s}^{-1} \text{ deg}^2$ or greater, so that a cloud with S_{CO} equal to that of the new cloud ($42.6 \text{ K km s}^{-1} \text{ deg}^2$ at 3 kpc) would be designated a cloud if it were closer than 7 kpc from the Sun. Unfortunately, the method used in the analysis by Dame *et al.* (1985) to separate

TABLE 1
CLOUD PARAMETERS

Parameter	Value
$S_{\text{CO}} = \int W_{\text{CO}} d\Omega$..	$42.6 \text{ K km s}^{-1} \text{ deg}^2$
Area	$1.6 \times 10^4 \text{ pc}^2$
$\langle v_{\text{LSR}} \rangle^a$	27 km s^{-1}
$\langle \Delta v_{\text{FWHM}} \rangle^a$	8.5 km s^{-1}
Distance	3 kpc

CLOUD MASSES
($10^5 M_\odot$)

Region	M_{CO}	M_{vir}
$213^\circ < l < 217.2^\circ$	5.4	8.4
$217.2^\circ < l < 219^\circ$	1.2	1.0
Total cloud ^b	6.6	10.8
S287	0.7	1.4

^a Determined from average spectral line (Fig. 3a).

^b CO masses are additive; virial masses are not.

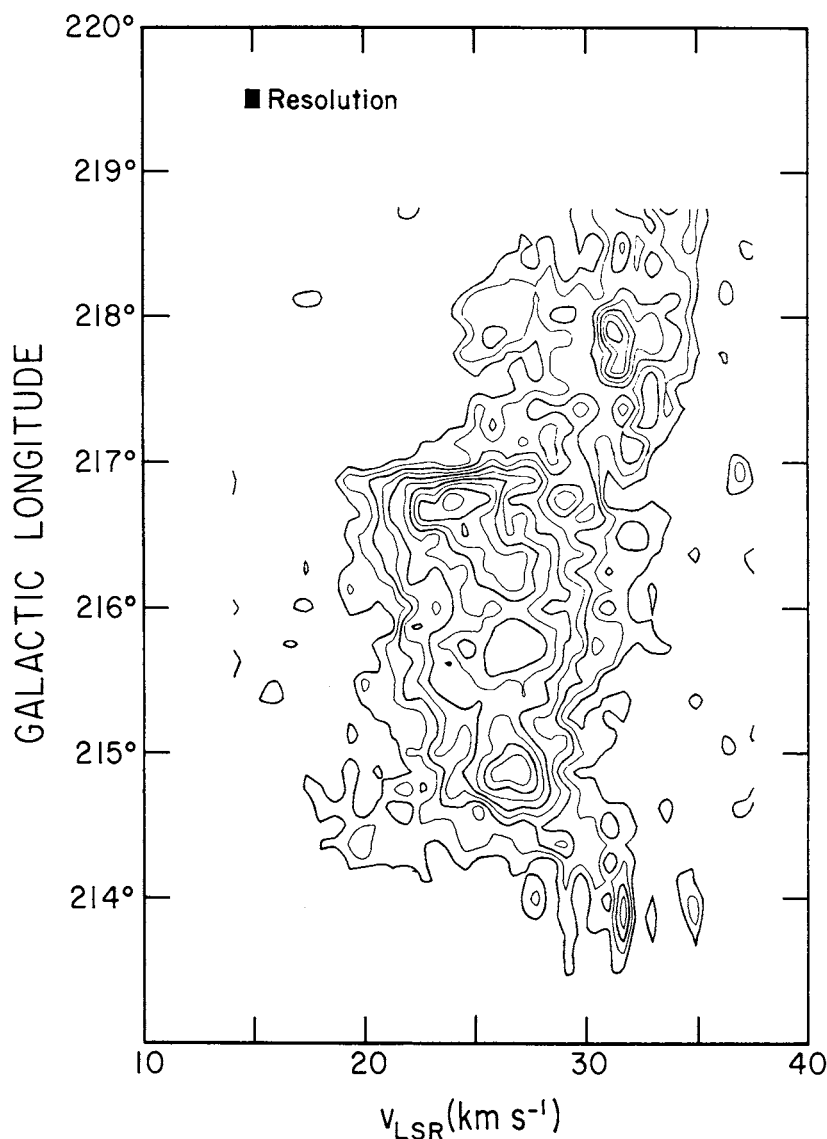


FIG. 4.—Velocity-longitude diagram for the new cloud constructed by integrating over the galactic latitude extent of the cloud ($b < -1^\circ$). The contour level and increment is 0.24 K.

clouds from the diffuse CO background emission can also remove clouds with temperatures as low as that of the new cloud, and so we expect difficulty finding such clouds in the deep inner Galaxy.

Nevertheless, we find two clouds, designated (39, 32) and (41, 37) by Dame *et al.* (1985), with $T_R < 2.5$ K and large spectral line widths (6 km s^{-1} FWHM). Located near each other, between $l = 38^\circ$ and 42° at $b \approx 0.5^\circ$, with a $v_{\text{LSR}} \approx 35 \text{ km s}^{-1}$ and at a distance of 2.2–2.6 kpc, and possibly associated with the W50 molecular cloud (Huang, Dame, and Thaddeus 1983), these two clouds may be a single object with a mass of $10^6 M_\odot$ and a linear size about half that of the new cloud. Both are apparently devoid of the usual signs of associated star formation (e.g., H II regions or far-infrared sources, Myers *et al.* 1985).

We conclude that such clouds in the outer Galaxy are probably rare and are not, in terms of mass, a large fraction of the molecular gas. They could be more common in the inner

Galaxy, where they would tend to be confused with the CO emission from very small clouds. It is not clear that observations with higher angular resolution will be of much help in distinguishing such clouds.

e) Evolutionary State of Cloud

There is little evidence that the new cloud is currently forming stars. Although S287, which is at the same distance as this cloud, has at least three associated early-type stars (Moffat, Fitzgerald, and Jackson 1979), we find no stars of this type in the direction of the new cloud. If young stars were embedded in the cloud and were interacting with it, its far-infrared emission would probably be higher than was observed. Strong temperature peaks, a common sign of newly formed stars that interact with the parent molecular cloud, are absent. Since M_{CO} is comparable to M_{vir} , the internal pressure sources created, for example, by strong stellar winds from young stars or gas heated by recently formed stars are apparently absent. Radio

TABLE 2
 RADIO CONTINUUM SOURCES

Source	<i>l</i>	<i>b</i>	ν (MHz)	S^a (Jy)	Reference	α	Spectrum	u^b (pc cm ⁻²)	Star ^c
4C -02.28	214°7	-1°7	178	6.1	1	~0.3 ^d	thermal	~60. ^{d,e}	~O6 ^{d,e}
			408	~9. ^d	2				
			820	~10. ^d	3				
			1415 ^e	...	4				
OH 066	214.9	-3.8	178	<2.	1	> -0.6	nonthermal?	23.9	O9.5
			1415	0.62	4				
4C -03.24	215.4	-2.9	86	<20.	5	-2.6 to -1.4	nonthermal	<15.2	...
			178	2.9	1				
			1415	<0.16	4				
4C -03.25	215.8	-1.5	178	2.5	1	-0.7	nonthermal	22.7	...
			1415	0.53	4				
4C -05.24	217.6	-3.2	86	25.	5	-1.4	nonthermal	22.0	...
			178	5.2	1				
			1415	0.48	4				

^a Upper limits in flux densities are from the respective catalogs.

^b Excitation parameter using the flux density at the highest observed frequency and assuming a distance of 3 kpc.

^c Spectral type of ZAMS star which, if the source were thermal, could give the derived u . Used Table 2 of Panagia 1973.

^d Flux densities are not accurate and were derived, after subtracting an approximate galactic background flux, from published contour plots.

The α , u , and derived spectral type are approximations.

^e Source only partially covered by survey at 1415 MHz (Ehman, Dixon, and Kraus 1970) with no accurate flux density ascertainable at this frequency. Used observations at 820 MHz to derive u and stellar spectral type.

REFERENCES.—(1) Gower, Scott, and Wills 1967, (2) Haslam, Quigley, and Salter 1970; Haslam *et al.* 1982. (3) Berkhuijsen 1972. (4) Ehman, Dixon, and Kraus 1970. (5) Mills, Slee, and Hill 1958.

continuum data suggest that 4C -02.28 may be an H II region, but we cannot now say whether the H II region is associated with the cloud.

Unlike the new cloud, most molecular objects of its size and mass are cloud complexes consisting of a collection of individual clouds. The ragged internal structure of most complexes is usually attributed to the violent activity that accompanies massive star formation (e.g., H II region expansion, strong stellar winds, supernovae). Since the new cloud is a single, continuous object, these violent events most likely have not occurred near it.

The unusual spectra, as well as the absence of star formation, suggest three interpretations for the cloud. First, it may possibly be a member of a small population of objects that never form massive stars, although an object of such size and mass should gravitationally contract and form stars in a fairly short time. Second, even though the cloud may have formed stars in the past, it is now quiescent; but previous star formation which would have left evidence in the cloud's vicinity would have left the cloud more fragmented than it appears.

The third, and most plausible, possibility is that the cloud is young and in a stage of evolution prior to the start of star formation. A molecular cloud recently formed out of a diffuse H I cloud, for which line widths of approximately 10 km s⁻¹ are typical, may have line widths as large as those found for the new cloud. The short free-fall time for molecular clouds implies

that the new cloud will soon begin to form stars and that the cloud may, given enough time, mature into a typical cloud complex, similar in size, mass, and structure to the Orion complex (Fig. 1).

IV. CONCLUSION

In summary, we have found a large molecular cloud which has the unusual property of being both cold and quite massive, with wide CO lines across its entire face. If at 3 kpc, the cloud is one of the largest known, its size, 250 pc \times 100 pc, and mass, 7–11 $\times 10^5 M_{\odot}$, comparable to those of a typical molecular-cloud complex. Unlike a typical cloud complex, the new cloud is apparently a single, continuous object with, except for a possible H II region, no associated star formation, consistent with the idea that star formation and the disruptive activity associated with it has not yet occurred. Such objects are apparently rare in the Galaxy. It is a plausible inference that we have detected a young cloud not yet forming stars, which may evolve into a typical cloud complex when star formation occurs.

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APPENDIX

TELESCOPE AND OBSERVATIONAL TECHNIQUE

Before 1983 May the observations were taken with a room-temperature Schottky diode superheterodyne receiver (Cong, Kerr, and Mattauch 1979). Typical receiver-noise temperature was 900 K single sideband (SSB) and typical system-noise temperature (i.e., the noise contributed by both the receiver and the earth's atmosphere) was 2500 K SSB. When a cooled SIS receiver, developed by Pan *et al.* (1983), replaced the Schottky receiver, receiver-noise temperature and system-noise temperature were reduced dramat-

ically to less than 95 K SSB and 600 K SSB respectively. Because the new receiver is only 1% or less as sensitive in its image sideband as in its signal sideband, it is, unlike its predecessor, essentially a single-sideband receiver.

Periodically, we checked the telescope pointing accuracy by observing the radio limb of the Sun (Cohen 1978), and, as a daily check, we compared the intensity toward strong CO sources in Orion and Monoceros with those previously obtained. Spectra were calibrated, first, by antenna tipping before each day's observations, and, then, for each observation, by updating the value of receiver gain with a chopper-wheel calibration (Cohen 1978; Kutner 1978). We converted the temperatures in the spectra to radiation temperatures, T_R (Kutner and Ulich 1981), by assuming the source filled the beam of the telescope and correcting for beam efficiency (0.81 for the Schottky; 0.92 for the SIS).

Observations with the Schottky receiver were made by frequency switching, which changed the frequency of the receiver's local oscillator by 10 MHz. When CO emission was present along a particular line of sight, the resultant spectrum contained both signal and image lines separated by 10 MHz. A third-order baseline was fitted to the 20 channels on both sides of the signal and image lines for each spectrum, and, after baseline removal, spectra were folded by summing the signal and image lines. To be sure that the third-order fit did not distort line intensities, a large number of spectra were analyzed with a first-order baseline fitted through the half-dozen or so channels on either side of the signal and image lines; the resultant spectra were not as clean in appearance as in the third-order fit, but intensities were always the same to within 10%.

With the SIS receiver the observations were position-switched, which requires reference positions (found by previous frequency-switched observations to be devoid of CO emission) and gives nearly linear baselines over the full bandwidth of the instrument. A first-order baseline was removed from those channels devoid of CO emission.

The integration times for each observation, chosen to give an rms noise of 0.25 K in the resulting spectra, were typically 10 minutes with the Schottky receiver and 1.5 minutes with the SIS receiver.

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